STATISTICAL ANALYSIS OF MUNICIPAL HEAT SUPPLY

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Abstract. The paper focuses on municipal heat supply statistics and correlative analysis of ambient temperature, supply water temperature, return water temperature, heat power, and supply water flow. This research is based on the analysis of the data for 2011 supplied by the producer of thermal energy to provide information about the parameter dependence. Processing of static data and correlation analysis are performed with the help of MS Excel 2010 software programme. The results show dependence of the return water temperature on the supply water temperature, while the graphics with correlation fields shows a large scatter of data as well as the correlation lag, depending on the analysed period. The temperature correlation varies depending on the operating period.

Key words: heat power, district heating, supply water, temperature, correlation.

Introduction

Process automation is a priority for the modern systems control. Automation is used as a primary means for the process control, monitoring and data logging in the heating process. It is important to examine the municipal heat supply parameters to find the conditions that affect the transient process. It is important to find municipal heat supply disturbances affecting the control and technological process. A lot of control types and algorithms can be provided for each technological process. On the basis of information about disturbance influence on the heat production and heat transfer it becomes possible to improve the process control and make it more efficient.

For heat production all information about the internal boiler room parameters like pressure, air flow, gas flow, temperature, and produced heat is required. All the mentioned data can be acquired from the local devices that are installed for that purpose. The operator of the power plant has incomplete information about the heat supply network. Water pressure, water temperature, and water flow readings are considered as direct information about the heat supply network, however, this information depends on the disturbances in the network. These disturbances are manifested by return water pressure and temperature data, indirectly describing the on-going processes in the heat network. Data on heat supply network disturbances can be used for analysing and finding the way to forecast the results before the disturbance has happened.

Latvian climate conditions impose particular requirements on the heat energy supply. This especially concerns district heating systems (DHS) – the prevailing solution of heat supply to large cities (~80 % of the total number of heat energy users) [1]. District heating systems consist of centralized heat production facilities (power plants) with associated distribution network (municipal heat supply) [2]. The main task is to find the parameters that give the most accurate information about the disturbances in municipal heat supply (house internal space heating and hot water heating). To find the most accurate parameters that would help to forecast the disturbances it is necessary to analyse the operational data of the existing heat network. When this is done, it becomes possible to find the real disturbance effect on the network parameters in the researched objects. With the data available it will be possible to verify the previously formed forecasting theory based the two analysis models based on quasi-dynamic approach [3]. Theory shows the forecasting method for the critical point in DH (District heating) system, modelling structure of the temperature dynamics and heat consumption in DH system.

Today, municipal heat supply control is carried out through the ambient temperature. That gives an opportunity to operate at the most efficient supply temperature. Information about the existing process gave the chance to open discussion about the most optimal water flow and temperature conditions in DHS. Heat network operation with the optimal working parameters allows reducing heat losses, which has a positive effect on the thermal energy tariffs [4].

Research object and methods

The first researched object is Cesis city municipal DH plant with the full heat power output of 5.2 MW. The power plant includes three independent natural gas boilers. The boiler working sequence and boiler output depend on the heat demand. The first boiler power output is 1.2 MW; the power of the second and the third ones is 2 MW. The structure of the power plant is shown in Figure 1. Supply water temperature is adjusted according to the ambient temperature. The power plant is fully automated. Heat from the boiler is transferred to consumers through the pipelines to the heat substations in the buildings so that the heat supply is more stable than in case of direct house heating from the heat supply source.

The second researched object is Jelgava city municipal DH plant with the full heat power output of 127 MW. The power plant consists of four independent natural gas boilers and a cogeneration station with 4 independent natural gas combustion engines. The cogeneration station works independently with the maximum electric power of 4 MW and heat power of 5.2 MW. The heat output adjustment process is done manually by the heat supply operator. The structure of the power plant is shown in Figure 2. Supply water temperature is adjusted by the power plant operator manually depending on the ambient temperature.

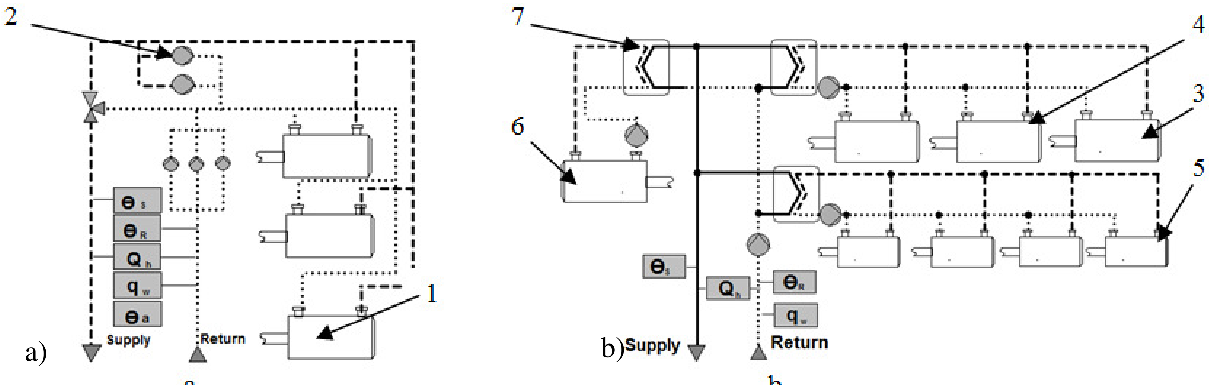

Fig. 1. **Block diagram of the city municipal DH plant setup:** a – Cesis city; b – Jelgava city; 1 – "KVGM-1.6" boiler; 2 – water pump; 3 – "KVGM-35" boiler; 4 – "PTVM-30M" boiler; 5 – "Jenbacher" cogeneration engine; 6. – "Vapor-8" boiler; 7 – heat exchanger

Information from the facility equipment is read by the process controller PM783. The programming logical controller (PLC) records information in the data monitoring system DigiVis. The monitoring system collects the necessary data in the trend acquisition logs. The following parameters are collected in the data logging system:

1. Θ_a – ambient temperature, °C;
2. Θ_S – supply water temperature, °C;
3. Θ_R – return water temperature, °C;
4. Q_h – heat power, MW;
5. q_w – water flow, $m^3 \cdot h^{-1}$.

The average interval of data logging is 5 s per each log line. The observation and data collection period covered one year - from January to December, 2011. During this period 6 062 754 logs had been recorded. In the one log line all the 5 necessary parameters are logged. It is important that the data is accurate in real time log. All data from the logged data files were transferred to the file having extension *.csv. The recorded file was then imported into the MS Excel software. Data sorting and detachment was done by using additionally written code in Visual Basic. For statistical analysis the mean values in the 10-minutes time period were used. The sorted data were analysed to obtain the standard statistical parameters. In order to check data correlation the data were analysed using MS Excel "Correlation" function.

Results and Discussions

In order to separate heating plant activities under different conditions the data array wasdiviced in two parts – winter period, where heating system activity is high, and summer period, where hating system acivity is rather low.

Winter period data analysis. The biggest consumption of primary resources is during winter period when the average day temperature falls below -5.0 ºC and more. The heating system during this period of time is operating to supply the heating systems of the buildings through substations and to heat up hot water for consumers – citizens living in the buildings. The first data analysis is performed for the period when in both cities it was cold with the mean ambient temperature falling down to -16.08 ºC in Cesis and -14.36 ºC in Jelgava. The selected date was 15.02.2011 (Fig. 1). All five variables were included in one graph with two vertical axes. The parameters Θ_a, Θ_S, Θ_R, and q_w are presented on primary axis. The parameter Q_h is presented on the secondary y axis.

Data graphs for both cities shows that at 6:00 the heat consumption increases. That is justified by pre-set substation temperature control program and hot water consumption. The heat consumption started decreasing starting from 8:30. This has a reasonable explanation: during daytime people leave their houses, and at the same time Θ_a increases to -10 ºC. In Cesis the lowest heat consumption period is from 12:00 till 17:30, while in Jelgava it was noticed that the lowest heat consumption is between 11:00 and 17:30. The main reasons for consumption decrease are the ambient temperature increase and lower hot water consumption.

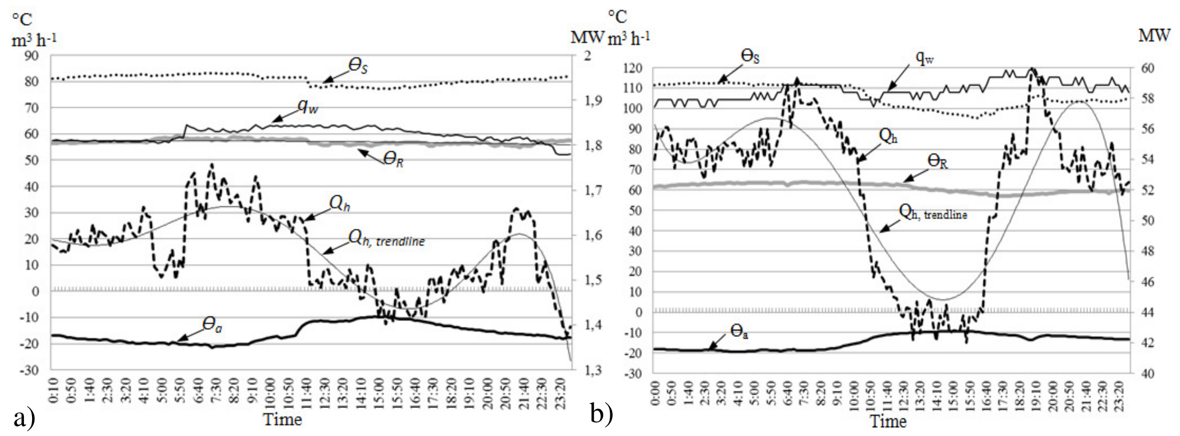

Fig. 1. **Municipal heat supply system parameters data plots:** a – Cesis city; b – Jelgava city

The main results of the 15.02.2011 day data statistical analysis are shown in Table 1 and Table 2. The first table shows analysed data statistical parameters. In the second table information about the correlation analysis results is presented. Θ_a and Θ_s correlation analysis shows that the parameters have close correlation ($|R^2|$ >0.96, which is explained by the operating process where the setpoint of Θ_s is a function of Θ_a (Fig. 2).

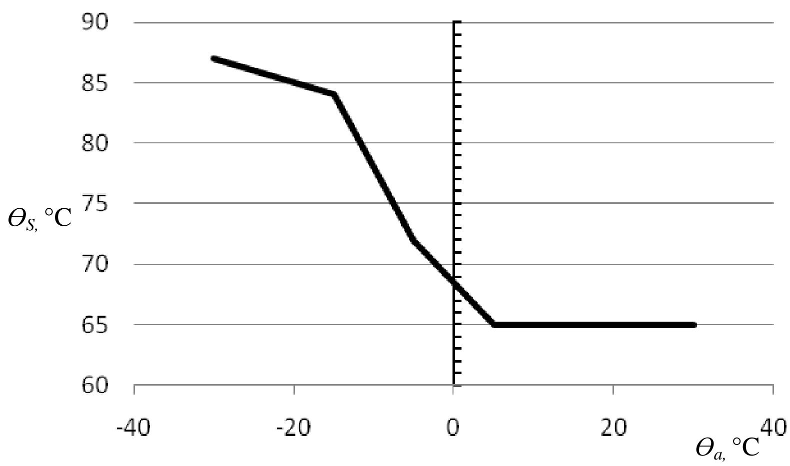

Fig. 2. **Cesis city Θ_S linear function of Θ_a**

The value of the actual Θ_s depends on the automatic control quality. In that case it is important to note that in Cesis the Θ_s is controlled by the process controller, while in Jelgava the Θ_s is controlled by the operator. That can be the reason why the Cesis city has stronger correlation of those two parameters.

Table 1

Cesis and Jelgava city heat supply network parameters statistical analysis

	Cesis city municipal					Jelgava city municipal				
Name	Θ_a, ºC	Θ_S, ºC	Θ_R, ºC	Q_h, MW	q_W, $m^3\ s^{-1}$	Θ_a, ºC	Θ_S, ºC	Θ_R, ºC	Q_h, MW	q_W, $m^3\ s^{-1}$
Count	144	144	144	144	144	144	144	144	144	144
Min	-21.41	77.24	54.80	1.38	52.10	-19.36	95.35	56.97	42.00	100.80
Max	-9.70	83.28	59.07	1.76	63.60	-9.26	112.60	63.90	60.20	118.80
Mean	-16.08	80.71	56.98	1.56	59.63	-14.36	105.93	61.12	52.22	109.03
Stand. dev.	3.58	1.87	0.92	0.09	2.74	3.70	5.62	2.23	4.96	4.38
Median	-16.93	81.23	56.76	1.56	59.55	-13.09	104.68	62.01	54.00	108.00

Table 2

Cesis and Jelgava city heat network parameters corelation analysis

	Cesis city municipal					Jelgava city municipal				
	Θ_a	Θ_S	Θ_R	Q_h	q_W	Θ_a	Θ_S	Θ_R	Q_h	q_W
Θ_a	1	–	–	–	–	1	–	–	–	–
Θ_S	-0.974	1	–	–	–	-0.968	1	–	–	–
Θ_R	-0.658*	0.679*	1	–	–	-0.753*	0.771*	1	–	–
Q_h	-0.697	0.721	0.390*	1	–	-0.701	0.730	0.207*	1	–
q_W	0.385*	-0.348*	0.068*	0.205	1	0.404*	-0.426*	-0.639*	0.242	1

*p>0.05

Θ_R correlation with Θ_a and Θ_S is higher in Jelgava. This is very important because the Jelgava city heat network is bigger in size and the boiler house power output is higher, but the results mean that in contrast to Cesis municipal heat supply, Jelgava network does not have as much unknown disturbance on the heat line. Low correlation means that in the municipal heat network there is unknown disturbance that has to be explained mathematically. The parameter Q_h correlativeness to Θ_R and Θ_S and q_W is explained by the heat consumption calculation formula. The heat consumption is calculated based on the temperature difference and water flow. In $R(\Theta_a;\ Q_h)$ correlation the variable Q_h is not causally fully dependent on the Θ_a because the Θ_a does not impact direct Q_h changes. [4]

Summer period data analysis. When the average value of the ambient temperature is above 5 ºC the heat consumption decreases and the process parameters in the heat network are not the same as in the period of higher heat consumption. Figure 6 shows the process for the 24 hours where the average temperature is 5 ºC in Cesis and 8 ºC in Jelgava. The operating process in Cesis in more stable and shows that there is no high heat consumption difference, but still the city is taking the load at 5:00 in the morning and around 22:00 the consumption decreases. Information in Figure 3 shows that the Θ_R in Cesis is more unstable in the process than it is in Jelgava. This can be explained by the difference in heat pipeline network size, because Cesis has a much smaller heat pipeline network than Jelgava.

Data provided in Table 2 clearly shows that the municipal heat supply parameters are more unstable. The correlation between the Θ_a and Θ_S is smaller. This can be explained by the unstable temperature control on the supply part. In Jelgava city data Table 2 the correlation between the Θ_a and Θ_S is -0.201, which means that there is no acceptable correlation. Weak correlation can be explained by the human factor – operator's activity, which means that the operators failed to ensure that the process control is performed as properly as with the process controller. In Jelgava Θ_S has small correlation with all parameters, which can be explained by low correlation with the primary linear source Θ_a. In this case it is important to note that Θ_S in summer period in relation to actual Θ_a is not changing. This means that the Θ_S statistical parameters for both cities have to be better than in winter period.

Further examination of information from the statistical analysis shows that Cesis boiler house operates with worse Θ_S parameters. Standard deviation for warm period is 1.92, while in cold period it was 1.87. This means that the PID controller parameters have to be readjusted according to the heating period. At the present moment in the warm period, heat consumption is quite unstable with high deviation from the average value and the PID controller is unable to maintain the temperature setpoint within the norm [7]. In Jelgava during this period the operators seem to hold the Θ_S more accurate than it was in the cold period. In reality, the summer period shows larger deviation of Θ_S.

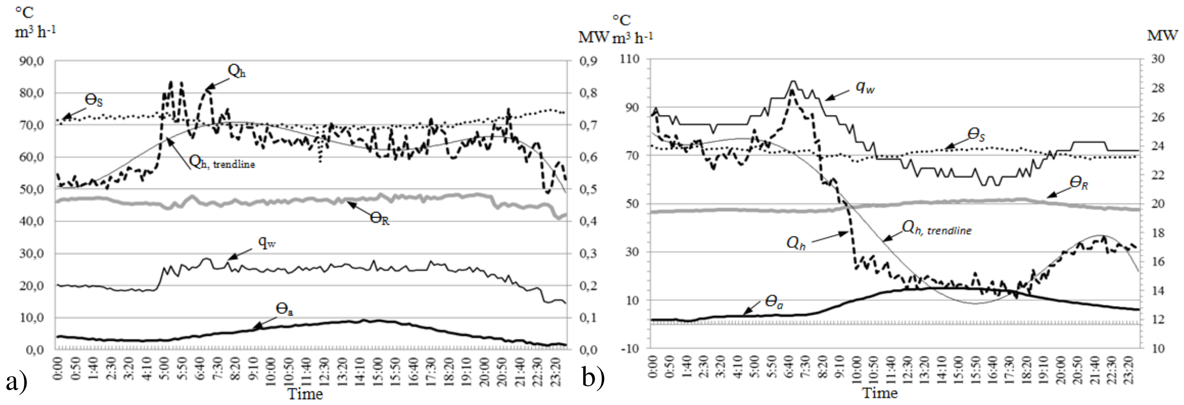

Fig. 3. **Factual municipal heat supply system parameters plot:** a – Cesis city; b – Jelgava city

Table 2

Cesis and Jelgava city heat network parameters of statistical analysis

	Cesis city municipal					Jelgava city municipal				
Name	Θ_a, ºC	Θ_S, ºC	Θ_R, ºC	Q_h, MW	q_W, m³ s⁻¹	Θ_a, ºC	Θ_S, ºC	Θ_R, ºC	Q_h, MW	q_W, m³ s⁻¹
Count	144	144	144	144	144	144	144	144	144	144
Min	1.33	58.56	40.91	0.49	14.40	1.27	67.56	46.38	13.40	57.60
Max	9.21	75.05	48.46	0.84	28.40	14.97	74.02	51.85	28.00	100.80
Average	5.14	70.91	46.22	0.63	23.08	8.43	71.27	48.79	18.89	75.68
Stand. dev.	2.30	1.92	1.33	0.07	3.34	4.73	1.58	1.68	4.44	11.13
Median	4.63	70.57	46.46	0.64	24.55	8.29	71.61	48.46	16.90	75.60
Correlation data										
	Θ_a	Θ_S	Θ_R	Q_h	q_W	Θ_a	Θ_S	Θ_R	Q_h	q_W
Θ_a	1	–	–	–	–	1	–	–	–	–
Θ_S	-0.808	1	–	–	–	-0.201	1	–	–	–
Θ_R	0.497	-0.494	1	–	–	0.934	0.023	1	–	–
Q_h	0.286	-0.327	-0.119	1	–	-0.920	0.325	-0.896	1	–
q_W	0.727	-0.727	0.468	0.763	1	-0.873	0.036	-0.911	0.946	1

The situation with the information for Cesis city regarding correlation information in Table 2 is different. The correlation results for winter and summer periods are different. Table 2 shows that q_W more correlative to all municipal heat supply parameters than it is in cold period with the average Θ_a = -16 ºC. Analysed data shows that the Q_h is less correlative with other parameters than in cold period. Such situation can be explained by unstable small deviation of the heat consumption. In summer period power plants are not working with the optimal heat load. This is the problem of the effective parameter control and regulation [8].

Conclusions

To conclude, the goal of this study was to answer the original research question of what is really happening in a municipal heat supply system and whether it is possible to forecast the result of the process from the start conditions, by analysing the process parameters from real municipal heat supply systems.

1. Analysed data shows that in winter period, when the power plant is working with the optimal output, the municipal heat supply system parameters are less disturbing and their correlation coefficients are more stable, which means there are less disturbances in the system and with the help of linear regression functions it is possible to calculate the process data and make forecasts for the power plant process control system.

2. In winter period regression coefficients R^2 for the function $R(\Theta_a; Q_h)$ in both cities are close by values. In Cesis R^2=0.4865 and in Jelgava R^2=0.4916, which shows that there is a ~50 % possibility to calculate the Q_h value with the help of the linear function $f(\Theta_a)= Q_h$.
3. Process parameter Θ_S control in the power plant is carried out with the function $f(\Theta_a)= \Theta_S$ with 97.4 % accuracy in Cesis and 96.8 % in Jelgava. Θ_S correlation with Θ_R is 0.679 in Cesis and 0.771 in Jelgava, which is important because Θ_R is one of the most important parameters for process automation control algorithms.
4. Automatic control system for Θ_S control has to be with the adaptive proportional-integral (PI) coefficients because municipal heat supply internal processes are with different reaction time depending on the day time. PI coefficients in summer period cannot be used in the same manner as they are used in winter period. They have to be adjusted.

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